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Numerical Investigation on Buckling Behaviour of a Non-Prismatic Double Corrugated Bridge Girder

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Abstract: The corrugated steel web is widely used nowadays as a structural element in the bridges due to its many favourable properties. Prior researches have shown that girders with steel corrugated webs (BGCWs) are an effective improvement in resisting the buckling when compared to conventional girder bridges. The studies have also shown that BGCWs buckle with three different modes; local, global and interactive buckling modes. This study is conducted to investigate the buckling behaviour of a non- prismatic bridge girder with double corrugated steel webs (BGDCWs). In this study the BGDCWs placed parallel and transverse having best taper ratio is obtained and arrangement of webs having least performance is strengthened using double corrugated stiffened girder (DCSG)and double corrugated composite girder (DCCG). The finite element modeling and analysis were carried out using the software ANSYS workbench 16.1. The results obtained shows that the taper ratio 3 is the best in both the cases of double web placed parallel and transverse. Further strengthening of double web placed parallel shows that DCCG has a higher axial load carrying capacity.

Keywords: Bridge girder, Double corrugated web, Taper ratio, Double corrugated stiffened girder, Double corrugated composite girder

I. INTRODUCTION

Girder bridges with girder beams as supporting member are of its simplest form. In girder bridges, the beams themselves are the primary support for deck and are responsible for transferring load to the foundation. Longer span, wider spacing of beams, more traffic on the bridge all directly result in the requirement of deeper beams in bridges. To overcome this to an extend Truss and arch style bridges can be provided, in which even though the girders are still the main support or the deck, the load is transferred through truss or arch to the foundation. This allows the bridges to span longer without increasing the depth of the beam beyond what is practical.

Recently, girders with steel corrugated webs (BGCWs) have been used as structural members in long span beams and bridges. The girders with corrugated webs are built up flexural members, consisting of a corrugated web that is welded to two flange plates. The girder bridges with corrugated steel webs are an effective improvement when compared to both conventional girder bridges and the classical steel concrete composite girder bridges by respectively replacing the concrete webs and stiffened flat steel webs with corrugated steel webs. Bridges with CSWs have many advantages over the bridges with conventional flat web girders. Their efficiency in avoiding the cracking of web of the girder is more compared to conventional girder. A bridge with corrugated web is eco-friendly because they emit the carbon dioxide 20% less than a concrete bridge and steel bridge. They have considerably high shear resistance and the reduction in web thickness in turn reduces the weight. Bridges with corrugated steel webs are economic and competitive for spans exceeding 100m. Other advantages include good aesthetic appearance, exhibiting defined forces, and being easy to construct.

Prior researches have shown that the corrugated webs, unlike flat webs, buckle with three different modes such as local, global and interactive buckling modes. A local shear buckling mode corresponds to the instability of a steel strip simply supported between two folds under uniform shear and they are critical in webs with deep folds. In local buckling, the corrugated web acts as a series of flat panels which are mutually supported each other along their vertical edges and supported by the flanges at their horizontal edges. The local buckling generally occurs from the lower part of the corrugated web near the ultimate load. This local buckling lowers the resistance and ductility of the member. The mode in which the entire corrugated steel web buckles is considered as global buckling mode and is critical for shallow folds. This mode consist multiple folds and the buckled shape extends diagonally over the depth of the web. The buckling having the characteristics of both local and global buckling modes is termed as interactive buckling mode. It is also the most difficult buckling modes to predict.

In modern construction, the demand for light weight as well as high performance structures is having very much importance. So, it is very necessary to examine the increase in strength with the increase in the weight of bridge girder with corrugated webs gained by increasing the thickness of web. A large increase in the weight of the bridge girder results only in a slight increase in the strength. So a bridge girder with corrugated web with smaller web thickness is more effective. This highlights the advantage of using double corrugated web plates in BGCWs as shown in fig 1.

This study is conducted to investigate the buckling behaviour of a non- prismatic bridge girder with double corrugated steel webs (BGDCWs). In this study the BGDCWs placed parallel and transverse having best taper ratio is obtained and arrangement of webs having least performance is strengthened using double corrugated stiffened girder (DCSG) and double corrugated composite girder (DCCG) using finite element analysis.

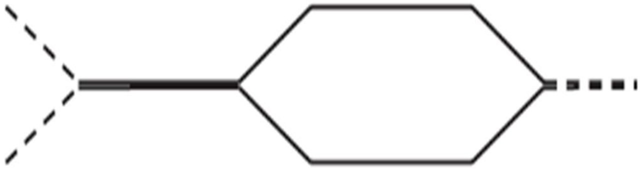


Fig. 1 Corrugation configuration of Double web

II. OBJECTIVES

The objectives of this study are:

A. To develop a non- prismatic bridge girder with double corrugated steel webs (BGDCWs) with the best taper ratio
B. To study the behaviour when the double corrugated webs are placed parallel and transversely
C. To strengthen the weakest arrangement using double corrugated stiffened girder (DCSG) and double corrugated composite girder (DCCG)

III. MODELING

A large increase in the weight of the bridge girder results only in a slight increase in the strength. Therefore a bridge girder with corrugated web with smaller web thickness is more effective. So a non prismatic bridge girder with double corrugated web will be effective and is modeled. The BGDCWs is modeled for a span of 4.5m with a fixed support at both the ends. A two point loading is provided axially along the loading plate. The geometric and material properties of the specimen are taken from a study on the determination of patch loading resistance of girder with corrugated web conducted by B. Kovesdi et. al and are shown in Table I and Table II. The web and flanges of BGCW are constructed using steel. The strength of BGDCW is determined by a non- linear static analysis using finite element method. The finite element analysis FEA is the best available method to analyse the girder. In this investigation, the commercial finite element software package ANSYS 16.1 is used for the non linear FEA computations of BGDCW under consideration. ANSYS software has the ability to consider any nonlinearity in a given model.

Table I Geometric Properties of Specimen

Properties	Dimensions
Span (mm)	4500
Element	Solid 186
Flange width (mm)	225
Flange thickness (mm)	20
Web thickness (mm)	6

Table II Material Properties of Specimen

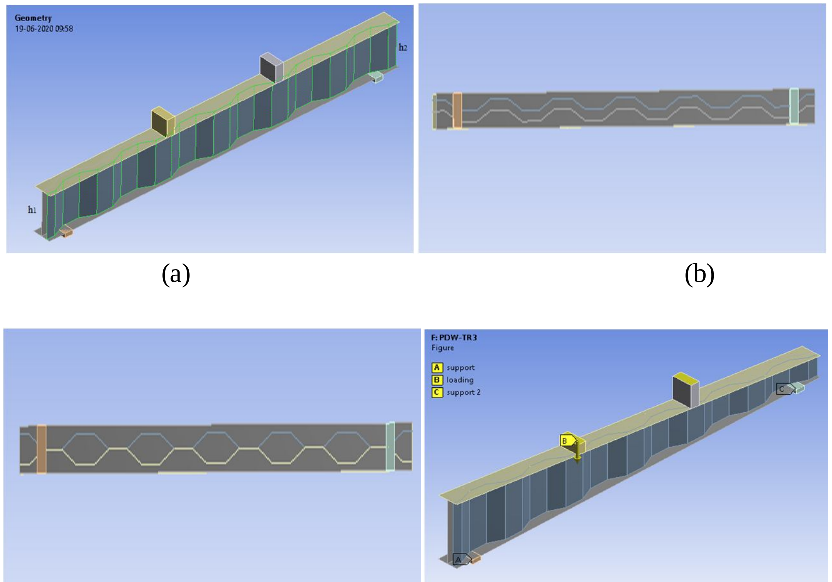
Properties	Value
Young’s Modulus (MPa)	2×10^5
Poisson’s ratio	0.3
Yield stress of web (MPa)	373
Yield stress of flange (MPa)	379
Ultimate stress of web (MPa)	542
Ultimate stress of flange (MPa)	517
Density (kg/m^3)	7850

A. *Case 1- Study on Taper Ratio*

Since tapered bridge girder is used for the study it is necessary to find out the model with best taper ratio. The double web is placed in two ways: parallel and transverse for taper ratios 2, 3 and 4. Study on prismatic girder is also done to check the performance compared to non prismatic girder. Heights of girder on either side are given in table III. Height of the girder h_1 and h_2 are taken by keeping the mass of the web equals to 110.42kg. ANSYS model of the BGDCWs is shown in Fig 2.

Table III Heights of Girder on Either Side

Taper Ratio	h_1 (mm)	h_2 (mm)
1(Prismatic)	500	500
2	670	335
3	750	250
4	800	200



(a) (b)

(c) (d)

Fig 2. (a) Prismatic girder (b) Webs placed parallel (c) Webs placed transverse (d) Loading and Boundary condition

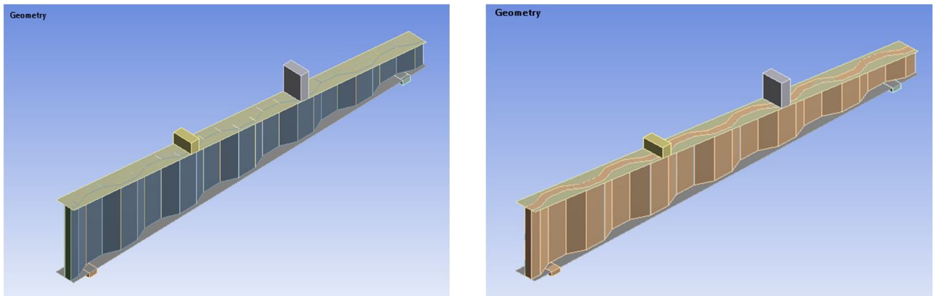
B. Case 2- Evaluating Strength of DCSG and DCCG

As per the previous study BGDCW with taper ratio 3 shows the best performance. But when comparing girders with double web placed parallel and transverse, those with double web placed parallel shows lesser strength. So this study aims at strengthening the BGDCW with web placed parallel by providing stiffeners (DCSG) and also by introducing concrete (DCCG).

In DCSG the bridge girder is provided with 26 numbers of equally spaced stiffeners along the span. The thickness of stiffener is provided as 6mm. The material properties of the stiffener are same as that of the web. In DCCG the concrete used is ultra-lightweight cement composites (ulcc) which is selected from a study done by *Jun- Yan Wang et.al* (2018). The material properties of ulcc are given in Table IV. ANSYS models of DCSG and DCCG are shown in Fig 3.

Table IV Material Properties of ulcc

Properties	Value
Density	1250 kg/m^3
Young’s Modulus	10620 MPa
Poisson’s Ratio	0.15



(a) (b)

Fig. 3 (a) DCSG (b) DCCG

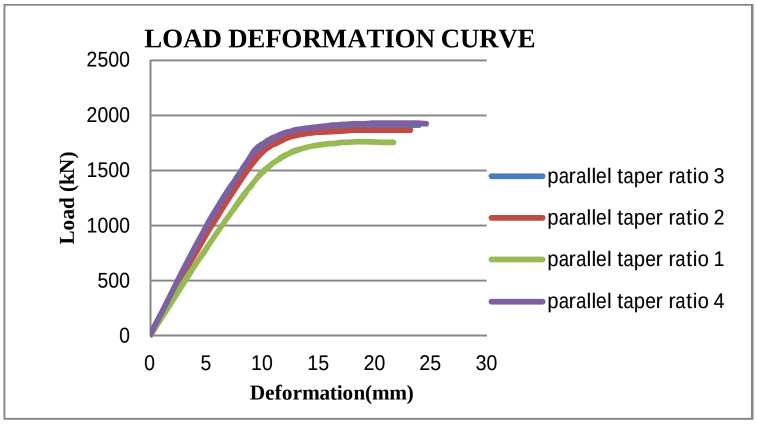
IV. ANALYSIS AND RESULT

The deformed shape of BGDCWs is analysed using the software ANSYS 16.1. Table V shows the load and corresponding deformation obtained for various taper ratios with double web placed parallel and transverse. From the Table it is clear that the bridge girder with double corrugated web having taper ratio 3 shows the best performance in both parallel and transverse cases. When comparing the double web placed parallel and transverse, the girder with web placed parallel shows least performance.

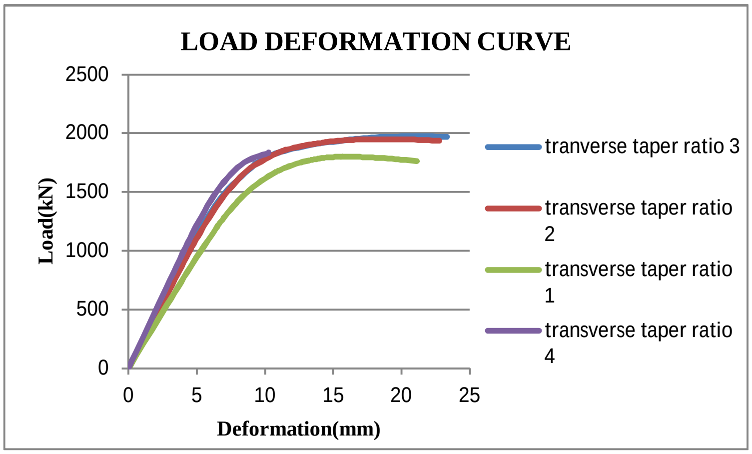
Table V Load and deformation of various taper ratios

Taper Ratio	Load (kN)		Deformation(mm)		% increase in strength	
	Parallel	Transverse	Parallel	Transverse	Parallel	Transverse
1	1760.00	1800.00	19.372	16.29	1.00	1.00
2	1870.00	1950.00	21.412	18.22	6.25	8.33
3	1910.00	1970.00	21.562	21.58	8.522	9.44
4	1880.00	1840.00	21.594	10.25	6.81	2.22

The Fig. 4 shows the load deformation curve of BGDCW with web placed parallel and transverse having various taper ratios. The load deformation curve of each model reaches a peak value. At the peak value the failure of the girder occurs and the load corresponding to the peak load is the maximum loading. The BGDCW placed transverse with taper ratio 3 has the maximum load at failure. The maximum load at failure is 1970.00 kN and corresponding deformation is 21.58 mm. Fig .5 shows the total deformation of BGDCW placed parallel.



(a) Parallel



(b) Transverse

Fig. 4 Load deformation curve

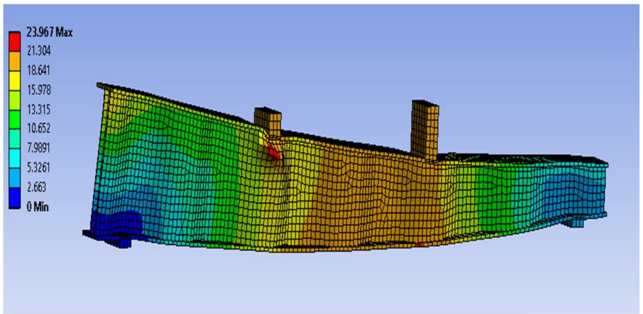


Fig. 5 Total deformation

The percentage variation in failure load and deformation of double corrugated stiffened girder (DCSG) and double corrugated composite girder (DCCG) is shown in Table IV. From the Table, it is clear that when comparing the load carrying capacity of DCCG and DCSG, the axial load carrying capacity of DCCG is increased by 25.095%. Fig 6 shows the load deformation curve of DCCG and DCSG

Table VI Percentage variation of failure load and deformation of DCSG and DCCG

Case	DCCG	DCSG	% Variation
Load (kN)	2630.00	1970.00	25.095%
Deformation (mm)	40.867	18.372	55.04%

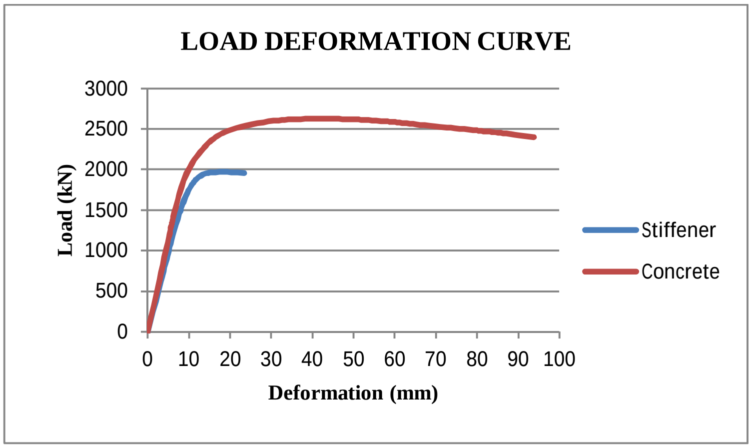


Fig. 5 Load deformation curve of DCCG and DCSG

The load deformation curves for both the models reach a peak point where the failure of girder occurs. It is clear that DCCG has the maximum load at failure. The load at failure of DCCG is 2630.00 kN with a deformation of 40.867 mm. Fig. 6 shows total deformation of DCCG.

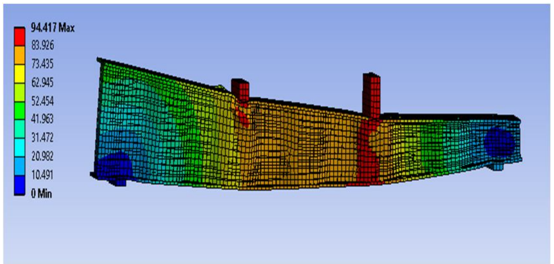


Fig. 6 Total deformation of DCCG

V. CONCLUSIONS

The study was carried out to investigate the local buckling and strengthening of bridge girder with double corrugated web (BGDCW) using Finite element modeling and analysis. The taper ratio study on bridge girder with double web placed parallel and transverse shows that taper ratio 3 has the maximum load carrying capacity. Further comparison made on bridge girder with double web placed parallel and transverse, those with the web placed transverse has the best result Compared to prismatic girders, the bridge girder with double web placed parallel has an increase in strength by 8.522% and those placed transverse has an increase in strength by 9.44%. The strengthening of bridge girder with double web placed parallel using providing stiffeners (DCSG) and filling the web with concrete (DCCG), the DCCG has an increase in axial load carrying capacity by 25.095%.

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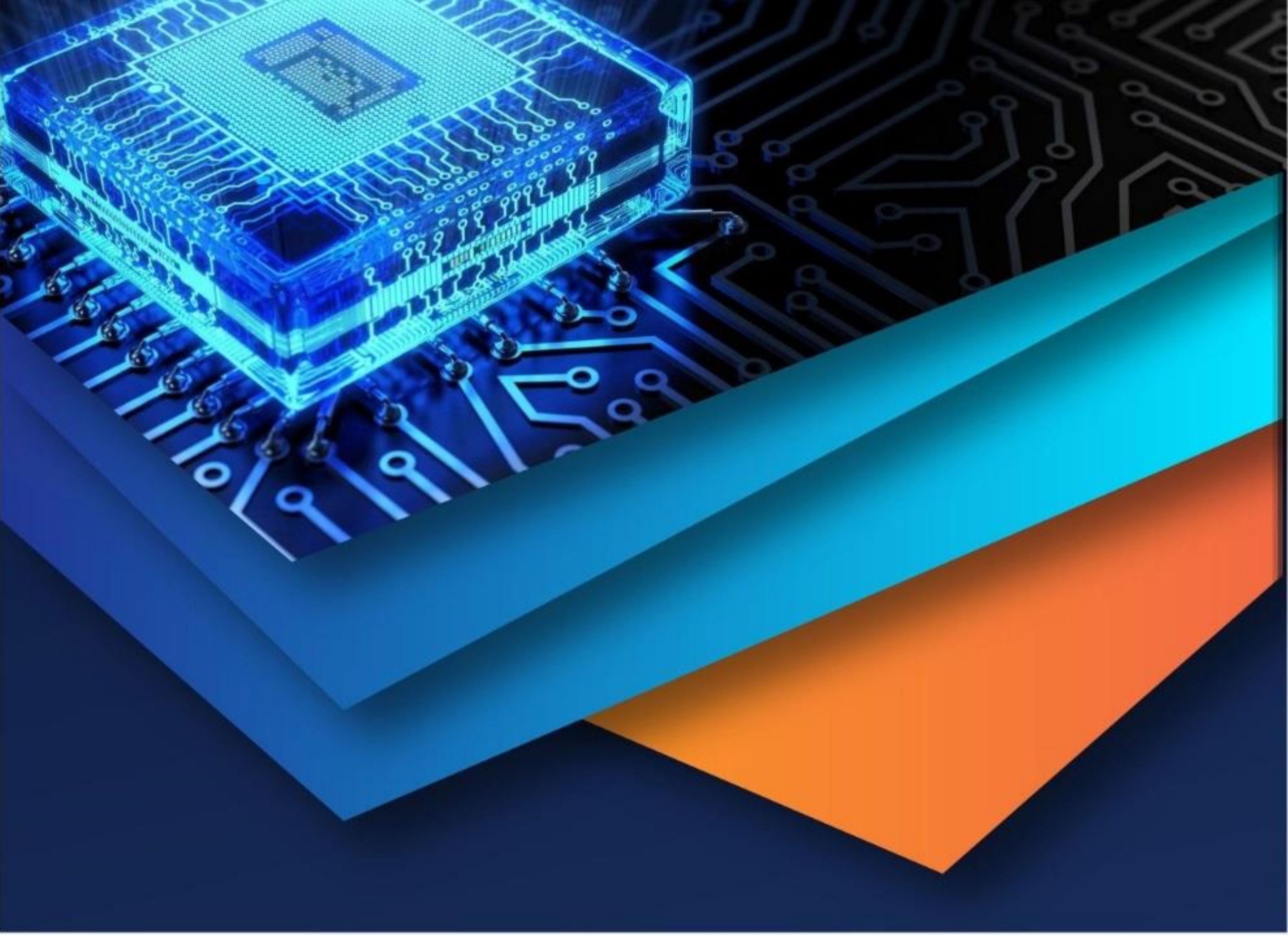

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